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ADAPTIVE ARCHITECTURE AND THE PREVENTION OF INFECTIONS IN HOSPITALS

Abstract

Researches has shown that climate change may spark global epidemics. The objectives of hospital design consistent with a high standard of sustainable architecture must not only be the tropicalization of buildings but also a system to confront the impact of infectious diseases which arise from climate change. Infection control is the discipline concerned with preventing nosocomial or healthcare-associated infection. Infection control addresses factors related to the spread of infections within the hospital building, including prevention, monitoring and management measures. As the application of new technologies such as the Heating, ventilation and air conditioning system (HVAC) with high-efficiency particulate arrestance (HEPA) has application range within stamina, the study suggests the need to adopt an integrated adaptive hospital design strategy to prevent infection.

Keywords:

Hospital, Infection, Transmission, Sustainability, Evolution, Ventilation.

1 INTRODUCTION

In current times, some hospitals have been pioneers in the application of new technologies. If unexpected factors appear in nature, that technological system may fail.

Review and analysis of the research on the impacts of climate changes on infectious diseases and the advanced theories of sustainability architecture in a warm climate context are necessary to form some of the effective architectural planning with appropriate design solutions of sustainable models for hospital buildings today.

Furthermore, the application of planning with clear hospital functional zonings, incorporating the flexibility and adaptive architecture design by modular solutions, simplified installation with system integration could meet the change of functional demands and the innovations of hospital facilities. Friendly environmental solutions provided alongside advanced technological systems will help prevent airborne infections as natural light is also a good germicidal factor. Therefore the application of adaptive transformable hospital architectural design appropriate to the context of each country is an innovative attitude of the current times.

2 REVIEW ON CONCEPTS OF ADAPTIVE ARCHITECTURE

The spectrum of sustainable architecture consists of efficient use of energy and material resource in the life-cycle of buildings, active involvement of the occupants into micro-climate control within the building, and the natural environment as the physical context [6]. Sustainable architecture may relate to or include the concepts of adaptive and evolutionary architecture

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It was broadly understood on the general definition that the sustainable architectural design in warm climate countries should focus on the efficient use of energy, material resource and micro-climate control within the building, as well as in the physical context of the natural environment to achieve the architectural tropicalization objectives of hospitals. But the current problem is many new architectural hospital design projects are unaware of the serious relations between climate change and emerging infectious diseases.

Adaptive modelling in entropy evolution is a design alternative for sustainable architecture. [7] The aim of an evolutionary architecture is to achieve in the built environment the symbiotic behaviour and metabolic balance found in the natural environment [1].

A hospital adaptive solution could be regarded as design that evolves and develops based on climatic and ecological elements, as well as advances in science and technology. The design is approached as a living organism as if natural forces had shaped the architecture.

3 REVIEW OF RESEARCH ON CLIMATE CHANGES AND THE MODES OF INFECTIOUS DISEASES TRANSMISSION

The most general definition of climate change: is a change in the statistical properties of the climate system when considered over long periods of time. The term climate change has become synonymous with anthropogenic global warming [8]. But the rise in temperature particularly in the warm climate areas is related to infectious diseases.

Zoologist Daniel Brooks said: "There is an enormous possibility of diseases passing to new hosts...It's going to intensify as climate change progresses." [4]. Climate change plays an important role which affects infectious disease occurrence which leads to an apparent increase in many infectious diseases, particularly some newly-circulating ones which vary greatly in their mode of transmission and type including the viruses, bacteria, protozoa and multicellular parasites. Changes in infectious disease transmission patterns are a likely major consequence of climate change.

A warming and unstable climate is playing an ever-increasing role in driving the global emergence, resurgence and redistribution of infectious diseases [10], while climate temperature affects their growth and survival. Other infectious diseases, such as salmonellosis cholera and giardiasis, may show increased outbreaks due to elevated temperature and flooding [5]. Climate change helps cholera and salmonella outbreaks. [6]

So climate change is a factor that in many cases, particularly global warming, could help viruses expand their range and make a comeback. New scientific research has shown that climate changes may spark a whole host of similar, global epidemics recently spread into unexpected places, as climatic fluctuations have pushed species such as Ebola and the West Nile virus into new environments. The dependence on technological measures only will have risks when the mechanical ventilation systems of hospitals in some cases may be inept and increase the transport and dissemination of infectious agents. The definition of Nosocomial infections are infections that have been caught in a hospital.

Following are the modes of infection transmission which must be examined to find solutions to minimize the risk of transmission of infectious disease to new hosts.

3.1 Contact transmissions

Contact is the most common mode of transmission of infection in hospitals which may be subdivided into direct contact, indirect contact and contact with droplets.

Direct contact: Direct contact refers to person-to-person spread of microorganisms through physical contact between the infectious agent including the contaminated hands or gloves of health care worker with the skin or mucous membranes of the recipient. The installation of handwashing basins in hospitals is one of the ways to prevent transmission by the contact route.

Indirect contact: Indirect contact occurs when a susceptible person comes in contact with a contaminated object. Examples include door knobs, keyboards, fabrics where patients have open

wounds, invasive devices contacted. Specific detailing design for easy cleaning, disinfection, and sterilization of hospital objects are essential to prevent nosocomial infection acquired from contaminated items and equipment.

Contact with droplet transmission: A person with a droplet-spread released infected secretions that spread through the air to the oral or nasal mucous membranes of a person nearby. Microbes in droplet nuclei (mucus droplets) can travel up to about 1 meter. The droplets don't remain suspended in the air but settle on surfaces. Surfaces of materials of architectural elements such as partitions must be solid and smooth enough to be able to prevent the suspension of droplets.

3.2 Airborne transmission

Airborne transmission occurs when fine microbial particles or dust particles containing pathogens remain suspended in the air for a prolonged period, and then are spread widely by air currents and inhaled which may cause infection when a susceptible person inhaling the infectious air flow and dusts. A variety of airborne infections in susceptible hosts can result from exposure to clinically significant microorganisms released into the air when environmental reservoirs (i.e., soil, water, dust, and decaying organic matter) are disturbed particularly in the demolishing of buildings and brought indoors into a healthcare facility by people, air currents, water, construction materials, and equipment. The attendant microorganisms can proliferate in various indoor ecological niches and, if subsequently disburged into the air, serve as a source for airborne healthcare-associated infections [7]. The application of adaptive architecture can help reduce the demand for demolishing obsolete hospital buildings.

The transmission of pathogens through the air has been noticed long ago, but it was not solved effectively. The physical design of some hospitals have been pioneers in the application of new technologies such as the service system of advanced techniques, especially the Heating, Ventilation and Air Conditioning system (HVAC). Having sterile filtration is practical. However, placing complete faith in this system is not only a fashionable mode but a bit less of enlightenment on the trend of sustainable architecture era. Each technological system has application range within stamina. If unexpected factors appear in nature, that technological system may become a double-edged sword. Friendly environmental solutions should be provided alongside advanced technological systems as natural light is also a good germicidal factor to help prevent airborne infections.

3.3 Waterborne transmission

Hospital water is a source of infectious microorganisms when hospital buildings draw the infected water from the municipal water supply. Corrosion damaged distribution pipelines, storage tank, poor water system design and water stagnation are also other transmission factors. Examples of common waterborne pathogens bacteria found in potable water include *Legionella pneu - mophila*, *Stenotrophomonas maltophilia*, *Aeromonas spp.*, *Acinetobacter spp.*, *Enterobacter spp.*, *Flavobacterium spp.* [7] Which are amongst new environmental bacterias pathogens surviving in water distribution systems, some have found an ecologic niche in drinking and hot water supplies.

4 INCORPORATE APPROPRIATE AND ADVANCED TECHNOLOGIES OPTIMIZING HOSPITAL INFECTION PREVENTION POSSIBILITIES

A comprehensive planning and design solution will integrate multiple infrastructure systems, accommodate appropriate and future technologies with regulatory changes including the infection prevention measures to optimize building performance.

4.1 Achieve the flexibility of adaptive architecture by modular solutions, simplified installation, and system integration

The flexibility by modular solutions, simplified installation, and system integration in architecture design could easily meet the change in space and the innovations of hospital facilities. Most hospital buildings are routinely used for 50 years or more – but at the same time individual rooms may be changed or replaced after as few as seven years, as clinical methods and equipment

change to improve hospital performance [10]. In this way, the installation of new isolation rooms to prevent the transmission of pathogens through the air can be more easily done. The flexibility of the structural system must develop in many directions and many locations and create conditions for the development of interior space: flexibility in allowance of use function, flexibility in disposal flexibility, flexibility in the arrangement of space, shown in the ability of extending building blocks or connecting with urban infrastructure systems. The interactions amongst all the parameters compose a complex system of sustainable architecture design, of which the conventional linear and fragmented design technologies are insufficient to indicate holistic and ongoing environmental performance [9]. But special attention must be paid to the flexibility adaptation of the elements of the surgery or the Intensive Care Unit (ICU) zone.

Hospitals are responding with an acceptance of more generic and modular space, much less likely to be customized to the needs of a specific service. Modular solutions with simplified installation, and system integration that improves hospital performance should be applied to secure the flexibility and sustainability of the hospital building. R. Sprow [12] claimed that a frequently used planning module that fits these criteria is a bay size of 9.2 m x 9.2 m which neatly fits a cluster of 6 exam rooms with a 1.6 m corridor, or two patient rooms with a nominal width of 4 m, or a group of 6 parking spaces, this size module also is within the capacity of a minimum depth flat slab concrete structure or a simple steel structure, without long spans [12]. Experiments through practice in Viet Nam identified that a bay size of 8.4 m x 8.4 m meeting the demands of load bearing was linked to marketing responsiveness.

4.2 Planning with clear hospital functional zonings

Planning that is clear and modular can help the replacement of functions of whole architecture blocks. This planning solution enables the flexibility in changes of technological system, whether advanced or appropriate to meet the demands of infection prevention.

Clear functional zonings or composition of spaces must be done so that the traffic flow can be easily modified in accordance with the new selected technological system. Old systems are being replaced by electronic kiosks, computerized direction systems with more interactive systems. Therefore the traffic flow of all kinds of different patients and staff does not overlap and reduce the intensity of travelling, thus minimizing the possibilities of infection contact transmission. The choice of proper entry to connect from the urban infrastructure system is also important, particularly the main entrance, the entrance to the outpatient clinic and the emergency department must be visible for all, particularly patients.

Special attention must be paid to zones such as the ICU and the surgical zone that must be isolated from the main traffic routes, in particular the axis vertical traffic such as elevators shafts and staircases in order to reduce travelling intensity and avoid infected airflow from stack effect to minimize the effect of airborne transmission. A good example is the surgery zone in Cho Ray hospital which was located a distance from the main elevator lobby.

4.3 Adaptive and evolutionary architecture must give priority to the application of natural factors as environmental control measures for airborne infectious diseases

Long ago, Florence Nightingale, the first person to launch the hospital ward model, stated that natural daylight and fresh air are effective elements to sterilize and reduce the infection phenomenon in hospitals. Advanced research and experiments have shown the effective solutions:

4.3.1 Enhance natural ventilation to reduce the intensity of airborne infection sources.

Many reality cases occurred in the past and recent years had shown that the risk of transmission of airborne diseases can be lower in naturally ventilated spaces than in mechanically ventilated ones.

In the SARS outbreak of 2003 in Vietnam, the lives of several patients and healthcare workers in an international hospital relying on mechanical ventilation were lost, but no lives were lost in a local

hospital that is the the Tropical Medicine Institute at Bach Mai Hospita, Hanoi which used natural ventilation. The effect of natural ventilation to is to reduce the intensity of airborne infection sources to optimize hospital infection prevention possibilities

Case studies from China following the SARS outbreak indicate cross-ventilation is one of the most effective ways of controlling the SARS infection in hospitals, with high ventilation rates [15]. Another study of isolation wards in Chinese hospitals showed those with a high proportion of openable windows were more effective in preventing outbreak of SARS among health workers than other design [14]. So investigations go to a conclusion that:

1. To help prevent airborne infections, adequate ventilation in healthcare facilities in main hospital spaces are necessary.
2. For natural ventilation, the following minimum hourly averaged ventilation rates should be provided:
 - 160 l/s/patient (hourly average ventilation rate) for airborne precaution rooms (with a minimum of 80 l/s/patient) (note that this only applies to new health-care facilities and major renovations);
 - 60 l/s/patient for general wards and outpatient departments;
 - 2.5 l/s/m for corridors and other transient spaces without a fixed number of patients.

Tab. 1: Estimated air changes per hour and ventilation rate for a 7 m x 6 m x 3 m ward [2].

Openings	ACH	Ventilation rate (l/s)
Open window (100%) + open door	37	1300
Open window (50%) + open door	28	975
Open window (100%) + closed door	4.2	150

When natural ventilation alone cannot satisfy the recommended ventilation requirements, alternative ventilation systems, such as hybrid (mixed-mode) natural ventilation should be considered, and then if that is not enough, mechanical ventilation should be used [2].

4.3.2 Enhance the Sunlight – nature’s disinfectant by flexible building envelope elements of rooms and corridors

From the ancient times, it was understood that rooms full of daylight are healthier than those in shadow and darkness. In the 19th century, investigations proved that sunlight inhibited the development of bacteria in laboratory test equipments and has a bactericidal effect. Rober Koch the famous German physicist and bacteriologist announced at the Berlin International Medical Congress in 1890 that sunlight was lethal to the tubercle bacillus. Experiments undertaken in the USA and the UK between 1941 and 1944 demonstrated the extraordinary and remarkable effectiveness of daylight in killing the bacteria streptococci [3]. The blue light in skylight was found to be particularly effective. Trials also examined the bactericidal effects of artificial light, which was found to have little value as a disinfecting agent. Even diffused daylight passing through two layers of glass from a north window was found to be highly effective in killing hemolytic streptococci within 13 days, with the same strain surviving in the dark, at room temperature, for 195 days [13]. Furthermore, patients assigned to rooms with an open view of a natural setting had shorter postoperative stays than rooms looked onto a solid wall.

As natural ventilation and lighting are also good germicidal factors and prevent infection. There should be open space so that the natural air and light enters the rooms and corridors. Therefore, the solution of wards, middle corridors, loop corridors (square or round) or closed U-shaped wards that the foreign architects often design based entirely on the air conditioning system with disinfectant filtration systems cannot be completely trusted. The pathogen usually is transmitted by air focus significantly at middle corridors of inpatient wards. Therefore layout of wards with side corridors are favourable. If this cannot be applied due to economic considerations, then some parts of the corridor

should be openable. Wards with pavilion types should not be closed at the ends to ease ventilation or space extension when necessary.

The diagnosis and treatment divisions with high requirements of sterilization should have an isolation room at the entrance. Therefore isolation rooms before the entrance to the areas requiring high sterilization using high air pressure in order to avoid infected air coming in must be flexible in the addition installation. The substitution of automatic door handles at any places must be considered.

In order to minimize the direct transmission phenomenon, it is necessary to install sinks at many places which are easily identifiable and accessible. Nowadays, it is possible to reach the criteria of 1 washbasin/4 patients. A nurse can come into contact with patients more than 100 times per day, if there is not an accessible hand basin, this would facilitate for disease transmission. These sinks do not coincide with the sinks in the restroom of the patient rooms in the previous plans or arranged in front of the bathroom doors. The partitions or walls on the ward corridors must be designed to be strong and solid enough to have separate sinks fixed on when necessary, outside any expected patient rooms. The arrangement of sinks with hand sanitizer in front of the doors of every patient room also contributes to prevent the indirect transmission modes such as via keyboard, doorknobs and so on.



Fig. 2. Grall Hospital, built in 1879 with open side corridors. (Source: Author).



Fig. 3. Health workers on an open side corridor of Grall Hospital in 1947. (Source: Tim Doling)

4.3.3 Application of adaptive finishing materials and construction technologies solutions

It was also Florence Nightingale who stated that the plaster used in construction, which has many tiny voids, was thought to be the locality and transmission of pathogenic factors. So it is necessary to choose the type of plaster with high solidity or to use covering material such as special paints. The ceilings mostly should be the type of large plate, but do not use the removable type to every cell. In particular, the ceiling of the operating room and some other areas must be made by concrete placed monolithically, fixed by hidden light bulbs so that the workers replacing broken light bulbs shall come above to the ceiling instead of entering the operation room to change the bulbs.

In the case of designing the flexibility of a hospital building, the building components such as the structural columns and beams, floor slabs, roof and foundations are fixed, but the partitions could be movable. Even part of the building structure may be designed to change its characteristics or expand, particularly the components on the external envelop which are in accordance with the changes of operating functions and facilities of the hospital.

In reality, there are some successful hospital design works in Vietnam such as Grall Hospital, (fig. 2, fig. 3) originally built as an army barracks in 1879 and Cho Ray Hospital (fig 3) although built more than 30 years ago still has many advantages: the inpatient zones are flooded with natural day

light and ventilation through a wide side corridor, it saves energy efficiently and serves well for the recovery of patients' health. The operation zone is far from the elevator blocks and shafts. The walls are in metal panels which can be removed. Aluminum louvers are used instead of concrete solid types which can absorb heat and pathogens. . It was no surprise when the Architect of Cho Ray hospital was Takeo Sato, one of the masters of Japanese modern architecture.



Fig. 3. Cho Ray Hospital 1974 with wide side open corridors. (Source: Author)



Fig. 4. Vietnam Sweden Uông bi hospital inpatient room with openable window. [Source: Luu Quoc Hoa]

4.3.4 Create a healthy, friendly environment to achieve the sustainability features

Lastly, although not directly concerned with the infection prevention requirements, it is necessary to enhance natural day light and natural ventilation to create a healthy, friendly environment for people and nature by adaptive expandable architecture measures. In addition, create safe psychology for patients on vision and sound, clearly show the entrance, avoid corridors that are too long and avoid seeing unfavorable views.

Create spaces to install facilities as beds for relatives of patients in the patient rooms under the direction of doctors, do not misunderstand that modern hospitals are intolerant to the presence or care of relatives. Enhance the ability to facilitate for the treatment medical staff such as: select good places contacted directly with nature for station of nurses on duty, and have an internal communication system. Integrating large monitor screens into the hospital spaces makes it easy to put vital information into contextually appropriate locations as integrating information technology in the hospital now is an ultimate measure of this operational point of view.

When developing the quote: "A house is a machine for living in" of Le Corbusier, we can accept the dominance of the perspective: A hospital is not only a house but also a machine.

5 CONCLUSION

A hospital sustainable design project of our era in Vietnam should be an adaptive solution carried out by a unit of multidisciplinary professional including architects, electrical engineers, equipment engineers, interior designers, construction contractors, equipment suppliers, project managers, financial managers, board of directors with hospital medical staff and not missing infection prevention experts .

These experts in the above mentioned multidisciplinary unit must coordinate synchronously together in introducing and reviewing the most advanced technology solutions but flexible and appropriate with the Vietnam natural climate context, in line with requirements of infection prevention capacity to achieve a most sustainable hospital project.

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